MODELING THE NUTRITION-ENVIRONMENT NEXUS: COMPLETING THE CYCLE

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INTRODUCTION

The 1950s to the early 2000s saw dramatic change in the US dairy industry. Genetic improvement, advances in knowledge of dairy cattle nutrition, and other management improvements led to an increase in the national annual milk production of more than 50 million lbs from less than half the number of cows (~ 21 million cows in 1950 vs. ~ 9.2 million cows in 2000) (Blayney, 2004). With the increase in total milk production and productivity per cow came an intensification of dairy production due to decreases in the number of dairy farms and increases in the number of animals per farm (Blayney, 2004). The term Concentrated Animal Feeding Operations (CAFO) was introduced in the mid-1970s to begin regulation of large animal production facilities under the Clean Water Act, but it wasn't until the early 2000's that these regulations gained attention and required direct action of dairy producers to develop Nutrient Management Plans and apply for pollutant discharge permits (Hribar, 2010). Thus, although the field of dairy science continues to contribute to management improvements that increase milk production, industry objectives expanded around the turn of the century to include efforts to reduce the environmental impacts of dairy production and strengthen future sustainability of the industry. To support industry needs to increase production while reducing environmental consequences, dairy and agricultural science fields have and will continue to elucidate connections between management practices, production, and downstream environmental impacts. A key component of efforts to reduce environmental impact is the ability to quantify each impact under a variety of management practices. Because measurement of things like farm emissions, runoff, and leaching is impractical or infeasible, prediction and simulation models are necessary for evaluating dairy production's contributions to these environmental pollutants (Kohn, 2015).

FROM FEED TO THE ENVIRONMENT

Obvious connections between dairy production and the environment are the pathways from dairy feed digestion to the environment. These include enteric methane emissions, manure methane, ammonia and nitrous oxide emissions, and manure N and P runoff and leaching. As a potent Greenhouse Gas (GHG), reducing enteric and manure methane emissions could reduce contributions of dairy production to global climate change. Depending on storage practices, application rates, and nutrient concentrations, dairy manure can produce GHG emissions, cause build-up of nutrients in the soil, and contaminate water and air resources. Growing awareness of and popular press attention to dairy and animal agriculture contributions to carbon emissions, water contamination, and algal blooms (e.g. Gardiner, 2015), have made these important areas of focus. Although increased productivity itself has been demonstrated to reduce the GHG production per unit of milk (Capper and Bauman, 2012), nutritional efforts to improve dairy sustainability over the past 20 years have also focused on reducing enteric methane and manure nutrient concentrations. Development of models to predict and describe these processes have increased so that we can quantify and compare environmental impacts of competing dairy management practices within the larger context of food production.

Methods to reduce enteric methane through nutritional supplements and feeding strategies have been widely studied with variable success (Knapp et al., 2014). Models that can predict methane production under a range of animal and dietary conditions using varying degrees of empiricism and mechanism (e.g. Hristov et al., 2017; van Lingen et al., 2018; Rotz, 2017) are available and have proved useful in quantifying this source of GHG. Similarly, the connections between dairy cattle nutrition and manure N and P excretion have been extensively studied with models following suit (e.g. Reed et al., 2015; van Lingen et al., 2018; Powell and Broderick, 2011; Satter et al., 2005; NRC, 2001). This kind of information has been useful for more precisely and efficiently meeting nutrient requirements which can reduce feed costs while improving environmental metrics as well as for national GHG and non-point source pollutant inventories (Cerosaletti et al., 2004; Thoma et al., 2013).

However, nutritional interventions are only part of the dairy system and have a limitations in their scope to improve sustainability before they are constrained by economic or biological feasibility (e.g. Moraes et al., 2015). Manure management is, therefore, the next logical piece of the dairy nutrition-environment puzzle and one that has also received a lot of attention in the past decades. Continuing innovation in manure management includes anaerobic digestion, liquid-solid separation, and improved application recommendations, among others (Leytem et al., 2018). Similar to nutritional strategies, manure management innovation has been accompanied by models to quantify benefits of implementing these practices (Leytem et al., 2018) but have physical and economic limitations in the scope of their impact. Anaerobic digestion, for example, requires a large investment in equipment, and, without supplemental substrate for digestion, may not produce enough energy from manure alone to be practical (Innovation, 2014). Also, improvements in manure N storage and application methods have small opportunities for improvement in relation to whole farm N efficiency and may shift more N to the soil and increase potential losses from the field (Reed et al., 2017).

Combining models of dairy cattle nutrition and excretion with those of manure management and field scale crop and soil models, one can trace nutrients and quantify their environmental impact from the feed all the way to their air or water loss pathways. However, this is the point in the dairy nutrient cycle where most investigations have stopped. Although it is well known that mineral N fertilization influences nutritional quality of forages in mostly predictable ways (i.e. increasing CP and fiber content) (Coblentz et al., 2017), manure fertilization has less predictable quality outcomes, especially for warm season grasses (Peyraud and Astigarraga, 1998; Coblentz et al., 2017), which makes it difficult to connect nutrition in Year 1 to forage quality and subsequent excretion and environmental loss in Year 2. Closing this nutrient cycle is an important area of investigation for dairy scientists and will support holistic investigations into long term sustainable management practices to prevent shifting impacts from one location to another or from one year to the next.

CLOSING THE CYCLE

In order to evaluate dairy sustainability in a holistic, rigorous way, we need whole farm models that represent the latest state of knowledge and complete dairy nutrient cycles such that the downstream impacts of management choices can be evaluated. Few whole-farm dairy models exist compared to individual farm component models, such as stand-alone crop production, animal feeding, or soil and environmental quality models. Furthermore, existing whole-farm models all have limitations in their ability to completely represent the complexities of modern dairy farms and their technologies. IFSM, arguably the most comprehensive of existing dairy farm models, often uses algorithms developed from science of the 1980s and 1990s and so does not capture the most recent improvements in nutrition and manure management. Further, IFSM simulates one year at a time, which prevents evaluation of long-term nutrient cycling and use efficiency and carry-over effects of management practices between years.

For example, choice of fertilizer and crop rotation have been shown to have variable long-term impacts on things like soil organic carbon and N mineralization that impact soil fertility and thus crop production (Oberlitz et al., 2018; Poffenbarger et al., 2018; Zavattaro et al., 2017; Triberti et al., 2016). There is also evidence that manure N from dietary alfalfa N is more readily available to oats and corn than manure N from dietary corn N resulting in higher DM yields (Powell and Broderick, 2011; Powell et al., 2017). Incorporation of the relationships between diet ingredients, manure composition, and subsequent year crop quality will improve whole farm simulation models and allow investigations into longer term consequences of management choices like:

- How does herd nutrition management affect nutrient fate in crop uptake and crop quality?
- Does reduction in enteric methane shift emissions to manure or soil based on the amount of volatile solids excreted?
- What are the impacts of different manure wastes streams and application quantities and methods on crop feed quality and nutrient losses to the environment?

Further, since management decisions begin long before ration formulation or manure application, closing the gaps in dairy nutrient models will also help inform larger scale management decisions by answering questions such as:

- How do crop system choices (e.g., increasing perennial legume use) affect fertilizer purchase requirements, animal diet formulation, animal productivity, and post-animal nutrient availability for future crop and feed production?
- How does dairy nutrition affect changes in soil health parameters (erosion, soil carbon) and subsequent crop growth and farm productivity?

These are just a few of the systems questions that a modern, whole-farm dairy simulation model can help to answer. To continue to improve the sustainability of the dairy industry we must build on the progress of the past decades using modeling to integrate knowledge of all parts of the dairy system and think holistically about both short and long term impacts of management choices.

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